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Research Application Summary

Moisture stress reduces stomata conductance, growth and yield of soybean

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Abstract

Soybean [*Glycine max* (L) Merrill] yield amongst smallholder farmers in Kenya is low and range from 445-1200 kg ha-1. These low yields are attributed to various factors including moisture stress and use of poor agronomic practices. Optimization of soybean production would help reduce food, nutrition and income insecurity at household level in Kenya. An experiment was conducted to determine the effect of varying soil moisture regimes on stomata conductance, growth and yield of selected soybean cultivars under greenhouse conditions. The experiment was conducted as a randomized complete block design (RCBD) in a 4 by 6 factorial treatment arrangement with moisture regimes (80%, 60%, 40% and 20% of field capacity) as first factor and cultivars (Gazelle, Nyala, EAI 3600, DPSB 8, Hill and DPSB 19) as second factor. Collected data on stomata conductance, leaf area, root nodulation, grain yield and seed protein content were subjected to Analysis of Variance (ANOVA) using Linear Mixed Model in GENSTAT. Significantly different treatment means were separated using Tukey's test at (p 0.05). Moisture stress significantly reduced stomata conductance, leaf area, grain yield, protein content and root nodulation of all tested soybean cultivars. The degree of stress response however varied amongst soybean cultivars tested. Cultivar DPSB 19 is recommended for production under low moisture levels.

Key words: Food and income security, smallholder farmers, soybean production, water deficits

Résumé

Le rendement en soja [Glycine max (L) Merrill] parmi les petits agriculteurs au Kenya est faible et varie de 445 à 1 200 kg ha-1. Ces faibles rendements sont attribués à divers facteurs, notamment le stress hydrique et l'utilisation de mauvaises pratiques agronomiques. L'optimisation de la production de soja aiderait à réduire l'insécurité alimentaire, nutritionnelle et de revenu au niveau des ménages au Kenya. Une expérience a été menée pour déterminer l'effet de divers régimes d'humidité du sol sur la conductance des stomates, la croissance et le rendement de cultivars de soja sélectionnés dans des conditions de serre. L'expérience a été menée sous la forme d'un bloc aléatoire complet (BAC) dans un arrangement de traitement factoriel 4 x 6 avec des régimes d'humidité (80%, 60%, 40% et 20% de la capacité au champ) comme premier facteur et cultivars (Gazelle, Nyala, EAI 3600, DPSB 8, Hill et DPSB 19) comme deuxième facteur. Les données collectées sur la conductance des stomates, la surface foliaire, la nodulation racinaire, le rendement en grains et la teneur en protéines des graines ont été soumises à une analyse de variance (ANOVA) en utilisant le modèle mixte linéaire dans GENSTAT. Des moyens de traitement significativement différents ont été séparés en utilisant le test de Tukey à (p 0,05). Le stress hydrique a considérablement réduit la conductance des stomates, la surface foliaire, le rendement en grains, la teneur en protéines et la nodulation racinaire de tous les cultivars de soja testés. Le degré de réponse au stress variait cependant entre les cultivars de soja testés. Cultivar DPSB 19 est recommandé pour la production sous de faibles niveaux d'humidité.

Mots clés: Sécurité alimentaire et de revenu, petits exploitants agricoles, production de soja, déficits hydriques

Introduction

Soybean (*Glycine max* L. Merrill) is one of the most important legume crops with total production of 261.6 million metric tonnes worldwide. Soybean is the most traded amongst the major tropical legumes constituting 83.8% annual revenue from all legume crops combined, which is estimated at US$ 31.0 billion (Abate *et al.,* 2012). Changes in climatic conditions all over the world due to influence of global warming is however creating unusual weather phenomena often in form of water deficits limiting soybean production. Understanding the response of soybean to limited soil moisture stress and identification and use of moisture stress tolerant cultivars would help reduce impact of moisture stress and hasten soybean yield improvement (Farooq *et al.,* 2009). Soybean farming is the most cost-effective way resource-constrained smallholder farmers can use to maintain soil fertility of their lands as soybean helps to improve soil fertility through biological nitrogen fixation as soybean fixes between 44 to 103 kg N ha^{-1}. The potential of soybean to significantly contribute to food and nutrition security and to generate substantial income for farmers is however constrained by low yields arising from moisture stress effects amongst other biotic and abiotic stresses. Soybean yields obtained by smallholder farmers in Kenya range from 445-1200 kg ha^{-1} which is low compared to potential yields of 3,500 kg ha^{-1}. With an annual soybean production of 4,335 metric tonnes, the country fails to meet its annual soybean demand of 100,000 metric tonnes leaving a deficit of 95% which is cushioned through imports (Chianu *et al.,* 2009). Optimization of soybean production and consumption would therefore help alleviate malnutrition in children and nutritional deficiencies in the elderly and people living with HIV and Aids. In addition, increased soybean production would help narrow huge importations of soybean by the Kenyan Government and thus contribute to macroeconomic stability of the country. Apart from contributing to foreign exchange earnings through direct exports of the crop, soybean would also help provide raw materials to agro-based industries and in the process contribute to job creation in the country. Owing to its economic, nutritional and functional importance, soybean warrants its cultivation in Kenya where over 30% of children are malnourished, unemployment is over 40% and use of inorganic fertilizer is low (Jackson, 2016). It is with this understanding that a study was conducted to determine the effect of moisture regime on stomata conductance, growth and yield components of selected soybean cultivars in Kenya.

Materials and methods

The experiment was conducted under greenhouse conditions at Egerton University, Njoro, in Kenya during 2017/2018 season. A randomized complete block design with a 4 x 6 factorial treatment arrangement with 3 replications was used for the study. Soil moisture regimes at 80%, 60%, 40% and 20% of moisture level at field capacity (FC) constituted first factor while soybean cultivars (Gazelle, Nyala, EAI 3600, DPSB 4, Hill and DPSB 19) were a second factor. Soil moisture regimes were monitored using IMKO-HD2 time domain reflectometer (TDR). Data were collected on stomata conductance, leaf area, root nodulation, grain yield and seed protein content. Stomata conductance was measured at 13.00 hours using an AC-1 leaf porometer (Decagon) on a third trifoliate leaf from top of the plant. Leaf area was determined by measuring individual leaf length (l) and width (w) and multiplied the product by a coefficient (k) 0.67. Total nitrogen (N) was determined using Kjeldahl method and protein content was determined by multiplying N concentration by 6.25 (Bremner and Mulvaney, 1982). Counting of individual root nodules was done at 50% flowering and active nodules were pink to red in colour when cut open while inactive nodules were green to brown in colour Collected data were subjected to analysis of variance (ANOVA) using Genstat 18th Edition and significantly different treatment means were separated using Tukeys test at 5% level of significance.

Results and discussion

Except for seed protein content, moisture regimes and soybean cultivars had significant interactive effects on stomata conductance, leaf area and grain yield (Table 1). Highest interactive effect on stomata conductance, leaf area and grain yield for all cultivars were attained with highest moisture level of 80% FC. Cultivar DPSB 19 gave significantly higher grain yield (6.6g plant^{-1}) compared to all test cultivars. At the most limiting moisture level of 20% FC, stomatal conductance, leaf area and grain yield were not significantly different amongst cultivars. Seed protein content was significantly increased with increase in soil moisture level with the highest protein content of 28.39% attained at a moisture regime of 80% FC. Protein content amongst different soybean cultivars was not significantly different. Moisture stress significantly reduced both total number of nodules and number of effective nodules (Fig 1). Total number of nodules and number of effective nodules were 91.55% and 98.69% lower respectively at the most stressful moisture regime of 20% FC compared to number of effective nodules registered at the highest moisture regime of 80% FC.

Inhibitory effects of moisture stress on stomata conductance, leaf area, grain yield and root nodulation, as found in this study, have previously been reported in soybean (Amira and Abdul, 2014; Hossain *et al.,* 2014). Reduced soybean grain yield under moisture stress may be attributed to negative effects of moisture stress on leaf area and root nodulation which may have resulted in a reduction in translocation of assimilates to developing soybean pods (Amira and Abdul, 2014). Under moisture stress, soybean plants tend to close stomata to conserve water reducing transpiration loses which in turn limits carbon dioxide intake into leaves for photosynthesis (Flexas *et al.,* 2009). Biological nitrogen fixation is dependent on available soil moisture and reduced soil moisture affects carbon concentration, soybean root architecture, nodule number and nitrogenase activity (Kunert *et al.,* 2016). Higher numbers of effective nodules under higher moisture regime led to increased biological nitrogen fixation resulting in nitrogen concentrations in soybean seeds (Imsande,1988) translating into significantly higher seed protein content under optimal moisture regime of 80% FC.

Table 1. Effect of moisture regimes on stomata conductance, leaf area, grain yield and protein content of soybean under greenhouse conditions at Egerton University, Kenya

Soil water (FC %)	Cultivar	Stomata conductance mmol/m^{-2}s^{-1}	Leaf area (cm^2)	Grain yield (g plant^{-1})	Seed protein content (%)
80	Gazelle	21.51^{bcd}	633.4^{cde}	3.01^{bc}	28.04
	Nyala	18.23^{cdef}	692.4^{bcd}	2.44cde	27.42
	EAI 3600	30.14a	616.0^{cde}	3.00^{bcd}	29.60
	DPSB 8	21.23^{bcd}	880.6a	3.79^{b}	28.92
	Hill	14.66^{defg}	772.7^{abc}	3.53^{b}	28.35
	DPSB 19	28.72^{ab}	845.8^{ab}	6.16^{a}	28.02
60	Gazelle	14.68^{defg}	532.0d^{efg}	2.89^{bcd}	28.65
	Nyala	18.02c^{def}	611.9^{cde}	1.97^{def}	26.25
	EAI 3600	25.22^{abc}	568.9^{def}	2.82^{bcd}	27.16
	DPSB 8	9.18^{hij}	623.87^{cde}	1.79^{efg}	28.00
	Hill	20.42^{cde}	565.2^{def}	2.42^{cde}	27.58
	DPSB 19	13.37^{efgh}	521.2^{efg}	3.85^{b}	26.25
40	Gazelle	13.77^{defg}	307.9^{hij}	1.50^{efgh}	26.40
	Nyala	10.49^{fghi}	333.4^{hij}	1.49^{efgh}	25.71
	EAI 3600	14.57^{defg}	316.7^{hij}	1.63^{efg}	28.00
	DPSB 8	10.02^{fghi}	422.6^{fgh}	0.54^{hi}	27.77
	Hill	12.49^{fgh}	394.3^{ghi}	1.25^{fghi}	26.10
	DPSB 19	10.62^{fghi}	395.0^{ghi}	1.64^{efg}	24.69
20	Gazelle	2.98^{ij}	243.0^{ij}	0.59^{hi}	27.71
	Nyala	2.57^{j}	201.5j	0.99^{fghi}	26.83
	EAI 3600	3.31^{ij}	216.8^{j}	1.03^{fghi}	26.69
	DPSB 8	4.59^{ij}	242.9^{ij}	0.34^{i}	26.15
	Hill	3.02^{ij}	238.2^{ij}	0.94^{ghi}	25.35
	DPSB 19	3.20^{ij}	201.8^{j}	0.83^{ghi}	26.83
ρ-value		<.001	<.001	<.001	0.508
Main Effects					
FC %	80	22.41^{a}	740.3^{a}	3.66^{a}	28.39^{a}
	60	16.82^{b}	570.5^{b}	2.62^{b}	27.37^{ab}
	40	11.99^{c}	361.7^{c}	1.34^{c}	26.44^{b}
	20	3.28^{d}	224.0^{d}	0.79^{d}	26.59^{b}
ρ-value		<.001	<.001	<.001	<.001
Cultivar	Gazelle	13.24^{bc}	429.1^{b}	1.99^{bc}	27.70
	Nyala	12.33^{bc}	459.8^{b}	1.72^{bc}	26.55
	EAI 3600	18.31^{a}	429.8^{b}	2.12^{b}	27.85
	DPSB 8	11.26^{c}	542.5^{a}	1.62^{c}	27.71
	Hill	12.64^{bc}	492.6^{ab}	2.03^{b}	26.85
	DPSB 19	13.98^{b}	491.0^{ab}	3.12^{a}	26.45
ρ- value		<.001	<.001	<.001	0.064

Means followed by the same letters within a column do not differ significantly at ($P < 0.05$); FC = Field Capacity

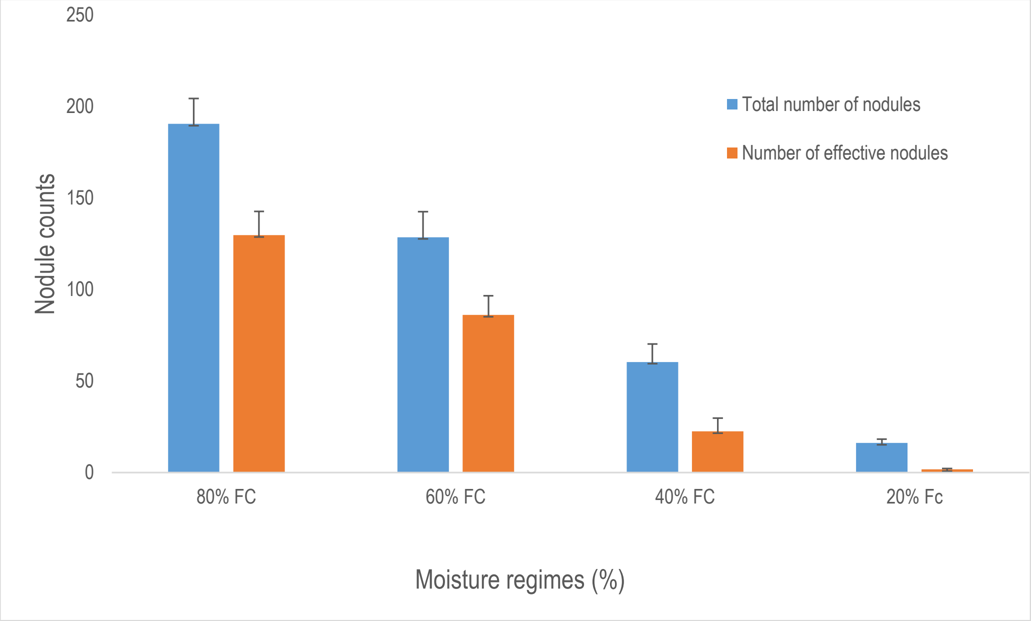

Figure 1. Root nodule counts at 4 moisture regimes

Conclusion

Preliminary results of the study have shown that moisture stress reduced soybean stomata conductance, leaf area, grain yield and root nodulation. Genotype DPSB 19 is recommended for production under limited moisture levels. There is however a need for repeat studies to validate these preliminary findings both under greenhouse and field conditions.

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References

Abate, T., Alene, A.D., Bergvinson, D., Shiferaw, B., Slim, S., Orr, S. and Asfaw, S. 2012. Tropical grain legumes in Africa and South Asia: Knowledge and Opportunities. Nairobi, Kenya: International Crops Research Institute for the Semi-Arid Tropics. 122pp.

Amira, M.S. and Abdul, Q. 2014. Effect of ascorbic acid antioxidant on soybean (*Glycine* max L.) plants grown under water stress conditions. *International Journal of Advanced Research in Biological Sciences* 1 (6): 189-205.

Bremner, J.M. and Mulvaney, C.S. 1982. Total nitrogen. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds). Methods of soil analysis: Chemical and Microbiological Properties.

American Social Agronomy, Madison, WI, USA: 595-624.

Chianu, J.N., Ohiokpehai, O., Vanlauwe, B., Adesina, A., De Groote, H. and Sanginga, N. 2009. Promoting a versatile but minor crop: Soybean in the farming systems of Kenya. *Journal of Sustainable Development in Africa* 10 (4): 324-344.

Farooq, M., Wahid, A., Kobayashi, N., Fugita, D. and Basra, S.M.A. 2009. Plant drought stress: effects, mechanisms and management. *Agronomy for Sustainable Development*, Springer Verlag/EDP Sciences/INRA 29 (1): 185-212.

Flexas, J., Baron, M., Bota, J., Galle, A., Galmes., J., Jimenez, M., Pou, A., Ribas-carbo, M., Sajnani, C., Tomas, M. and Medrano, H. 2009. Photosynthesis limitations during water stress acclimation and recovery in the drought adapted Vitis hybrid Richter-110 (*v. berlandieri x v. rupestris*). *Journal of Experimental Botany* 60: 2361-2377.

Hossain, M.M., Liu, X., Qi, X., Lam, H.M. and Zhang, J. 2014. Differences between soybean genotypes in physiological response to sequential soil drying and rewetting. *The Crop Journal* 2: 366-380.

Imsande, J. 1988. Enhanced nitrogen fixation increases net photosynthetic output and seed yield of hydroponically grown soybean. Journal of Experimental Botany 39: 1313-1321.

Jackson, A. S. 2016. A brief history of soybean production in Kenya. *Agriculture and Environment* 5 (2): 58-64.

Kunert, K.J., Volster, B.J., Fenta, B., Kibido, T., Dionisio, G. and Foyer, C. 2016. Drought responses in soybean roots and nodules. *Frontiers in Plant Science* 1015: 1-7.